

AD-A078 497

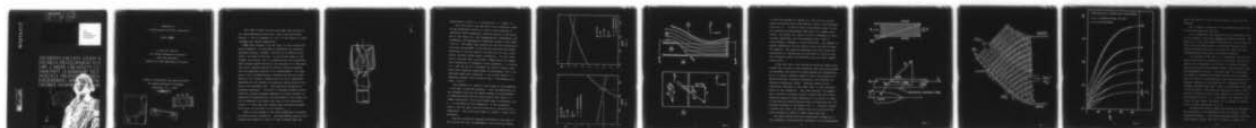
GEORGE WASHINGTON UNIV WASHINGTON D C SCHOOL OF ENGI--ETC F/G 21/2
RESEARCH ON CRYPTOSTEADY-FLOW THRUST GENERATORS.(U)
DEC 79

N00014-76-C-0649

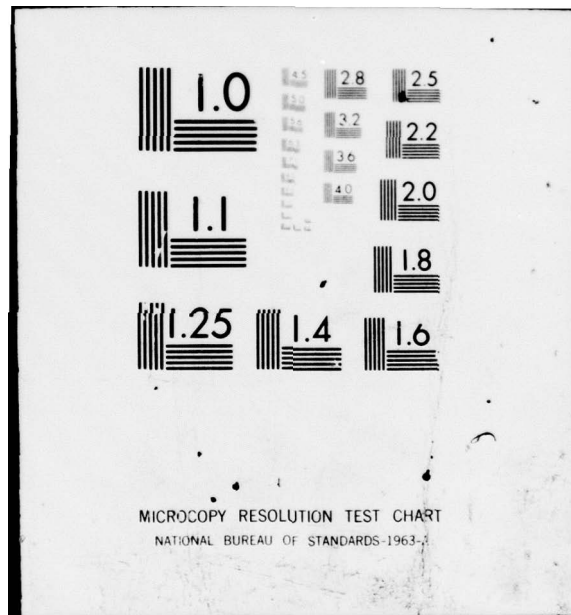
NL

UNCLASSIFIED

| OF |
AD
A078497



END
DATE
FILMED
1-80
DDC



ADA 078497

LEVEL 12

THE
GEORGE
WASHINGTON
UNIVERSITY

STUDENTS FACULTY STUDY R
ESEARCH DEVELOPMENT FUT
URE CAREER CREATIVITY CC
MMUNITY LEADERSHIP TECH
NOLOGY FRONTIER DESIGN
ENGINEERING APP ENC
GEORGE WASHINGTON UNIV

DDC FILE COPY

79-12 21 023



A



SCHOOL OF ENGINEERING
AND APPLIED SCIENCE

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED

6 Research on
Cryptosteady-Flow Thrust Generators.

9 FINAL REPORT. 1 Jan 76-31 Nov 79.

on the work done at
the George Washington University
under ONR Contracts

15 N00014-76-C-0649 and N00014-78-C-0454

School of Engineering and Applied Science
The George Washington University
Washington, D.C. 20052

11 Dec 1979

Accession For	
NTIS GMAI	<input checked="checked" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	<input type="checkbox"/>
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

12/26
DDC
RECEIVED
DEC 26 1979
A

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

153 370

mt

This report covers the work done under ONR Contract at the George Washington University, during the period from January 1, 1976 to November 30, 1979, on the subject of cryp-
tosteady flow thrust augmentation.

→ ^{THIS} ~~The~~ study focussed, from the start, on the "rotary-jet" thrust augments, as developed at Rensselaer and tested at MacDonnell-Douglas, Grumman, the Naval Air Propulsion Test Center, and other facilities. In this device (Fig. 1) the primary (or driving) flow is discharged into the interaction space through skewed nozzles on the periphery of a free-spinning rotor, thereby forming the helical rotating patterns that are sometimes referred to as "pseudoblades". The idea here is not to promote mixing (although this may be a side benefit), but rather to generate and utilize an additional mechanism for the transfer of mechanical energy from the primary to the secondary flow. This additional mechanism is "pressure exchange" -- the work of interface pressure forces. Since the pressure exchange component of energy transfer is essentially nondissipative, the performance of the rotary jet can be expected to be better than that of the conventional ejector -- a fact that had already been confirmed experimentally prior to the start of this project.

Work on this program at the George Washington University has been entirely theoretical. The experimental phase of the program was conducted at the U.S. Naval Academy under the

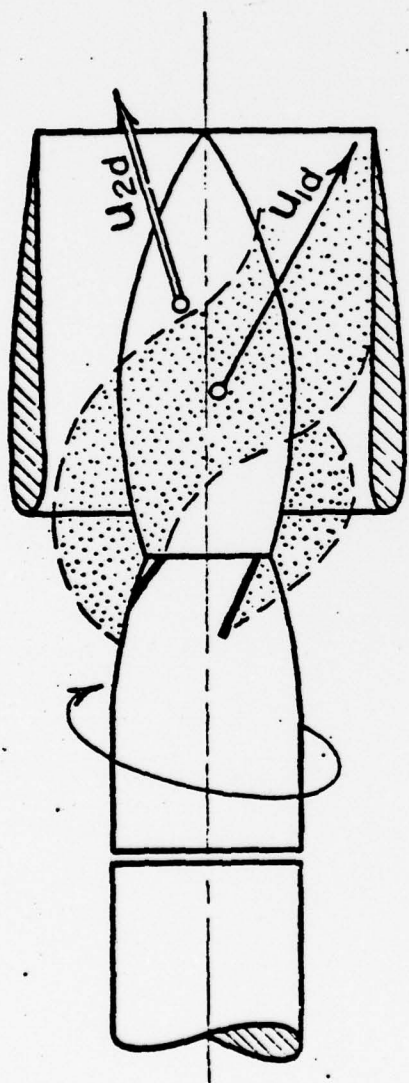


Fig. 1

supervision of Profs. A. A. Pouring and J. F. Sladky, Jr.

The first step in the GWU effort was to develop a generalized performance analysis to cover a whole spectrum of underwater thrust augmenters, from the ejector to the marjet and to the rotary jet, with incompressible, compressible noncondensing, and compressible condensing primary fluids (Refs. 1 and 2). The theory also accounts for the flow nonuniformities that are produced in the glancing collision and mutual deflection of the two flows at the beginning of their interaction, and has yielded useful information. Its main value lies in the fact that it provides a common basis for comparative evaluations of competing thrust augmenters. It reveals, e.g., that the use of a two-phase (air-water) primary could bring about important improvements of performance, and it establishes under what conditions -- and to what extent -- a condensing primary would be better than a noncondensing one (Figs. 2 and 3).

This analysis is, however, still based on the assumption -- also used in previous analyses -- that the penetration of the secondary flow into the spaces between the pseudoblades is completed before the two flows deflect each other to a common orientation in the rotor-fixed frame of reference (Fig. 4). On the basis of this assumption, if the interaction space is not too deep, the flow field can be treated as two-dimensional. This analytical model is, however, likely to be optimistic.

The only alternative approach available at the start of this project was that of Hohenemser's thin-jet-strip theory,

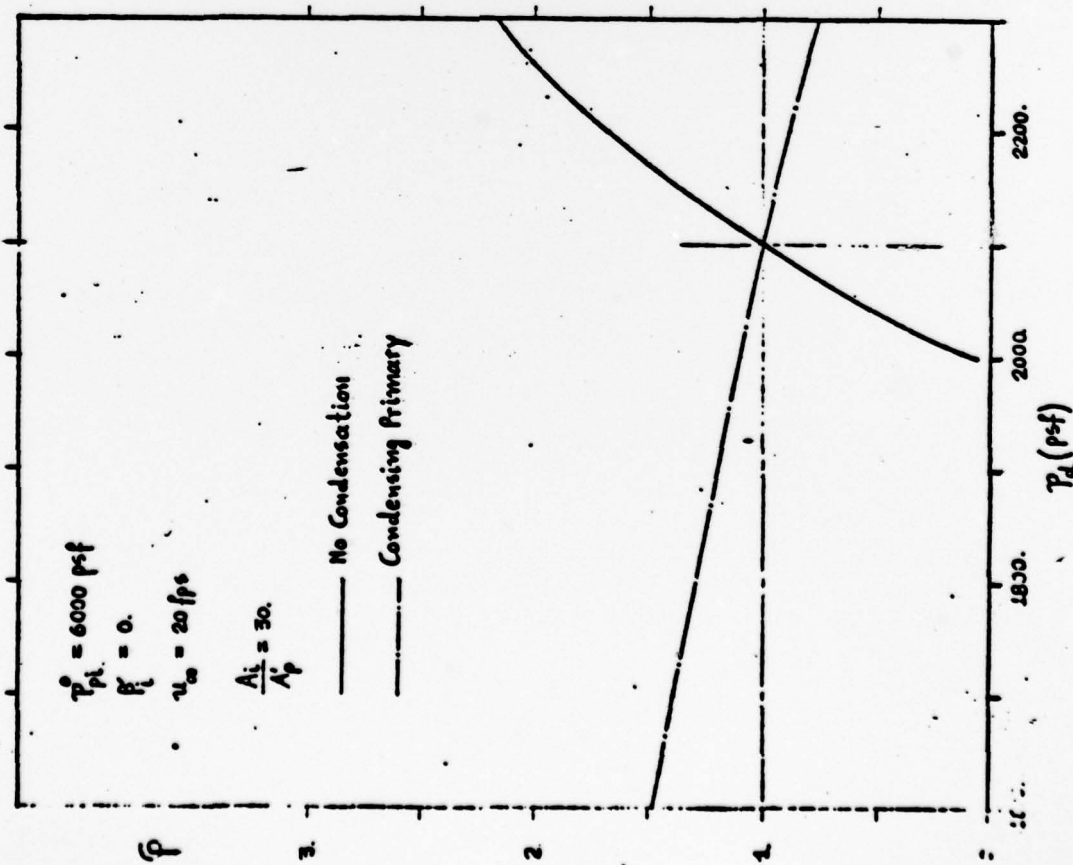


Fig. 2

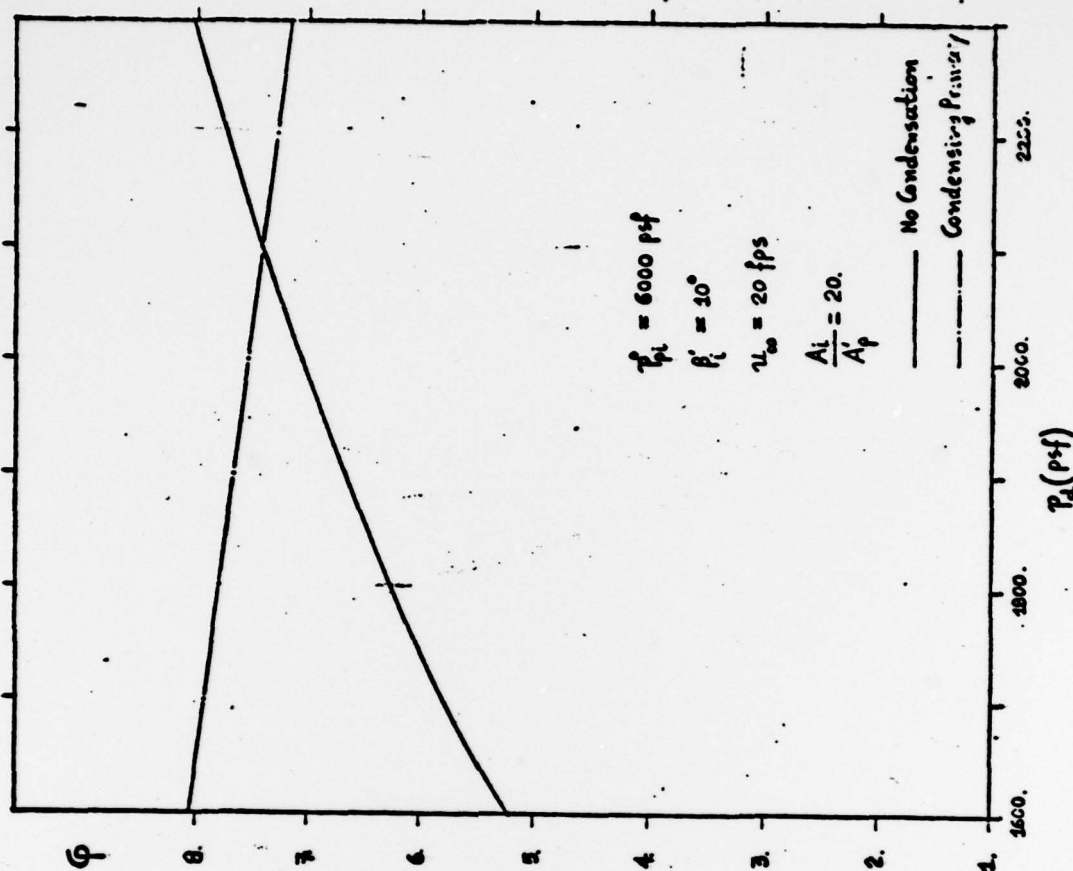
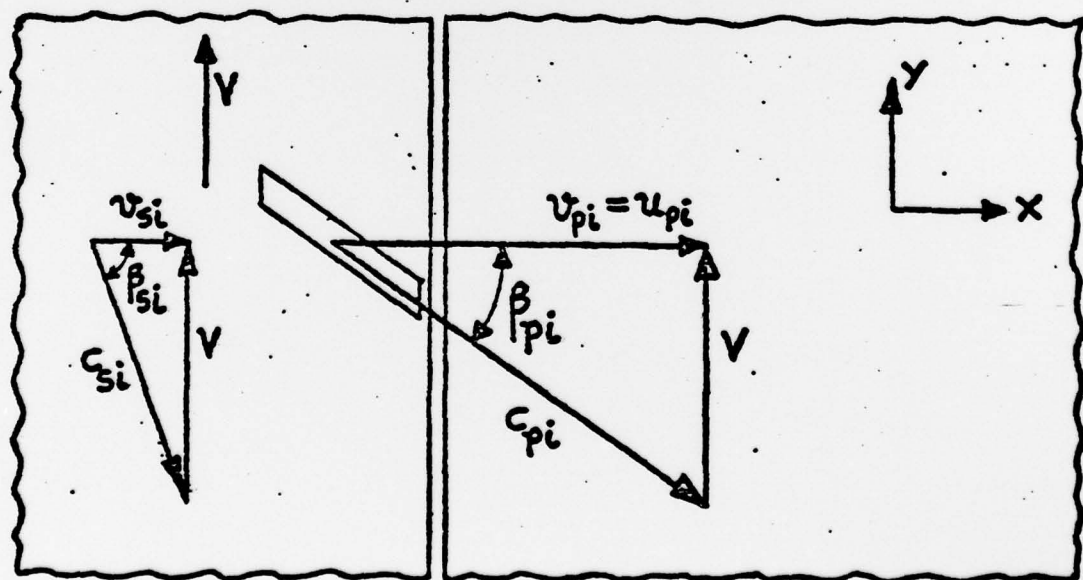
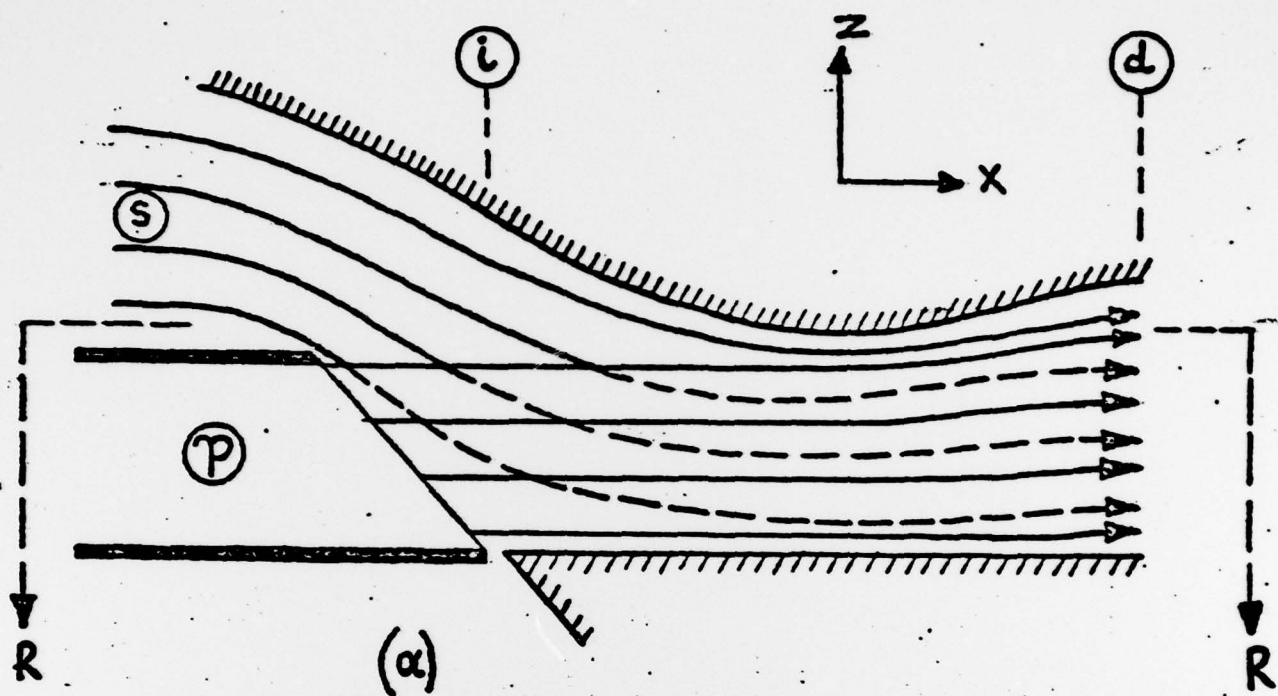


Fig. 3

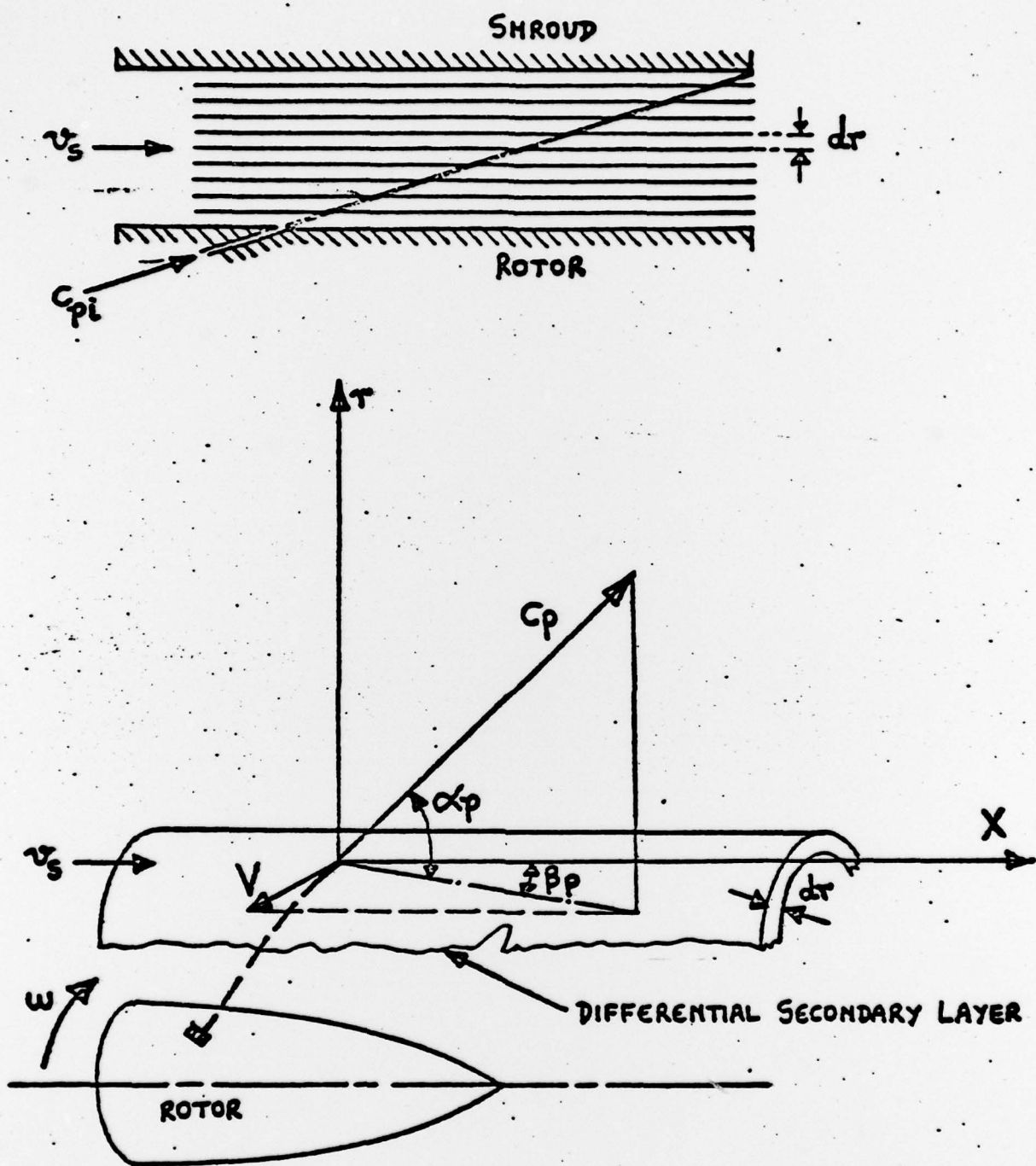


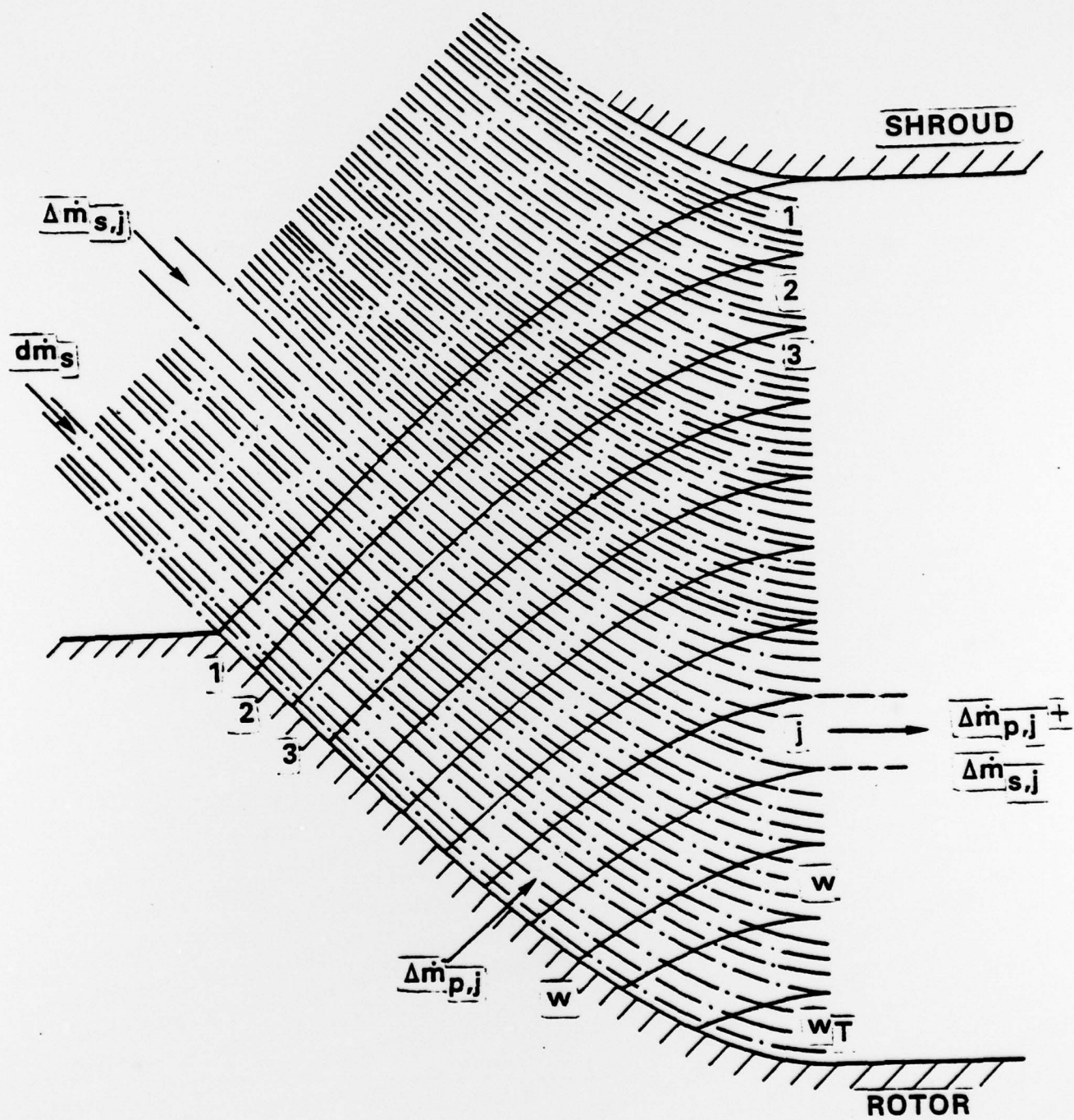
(b)

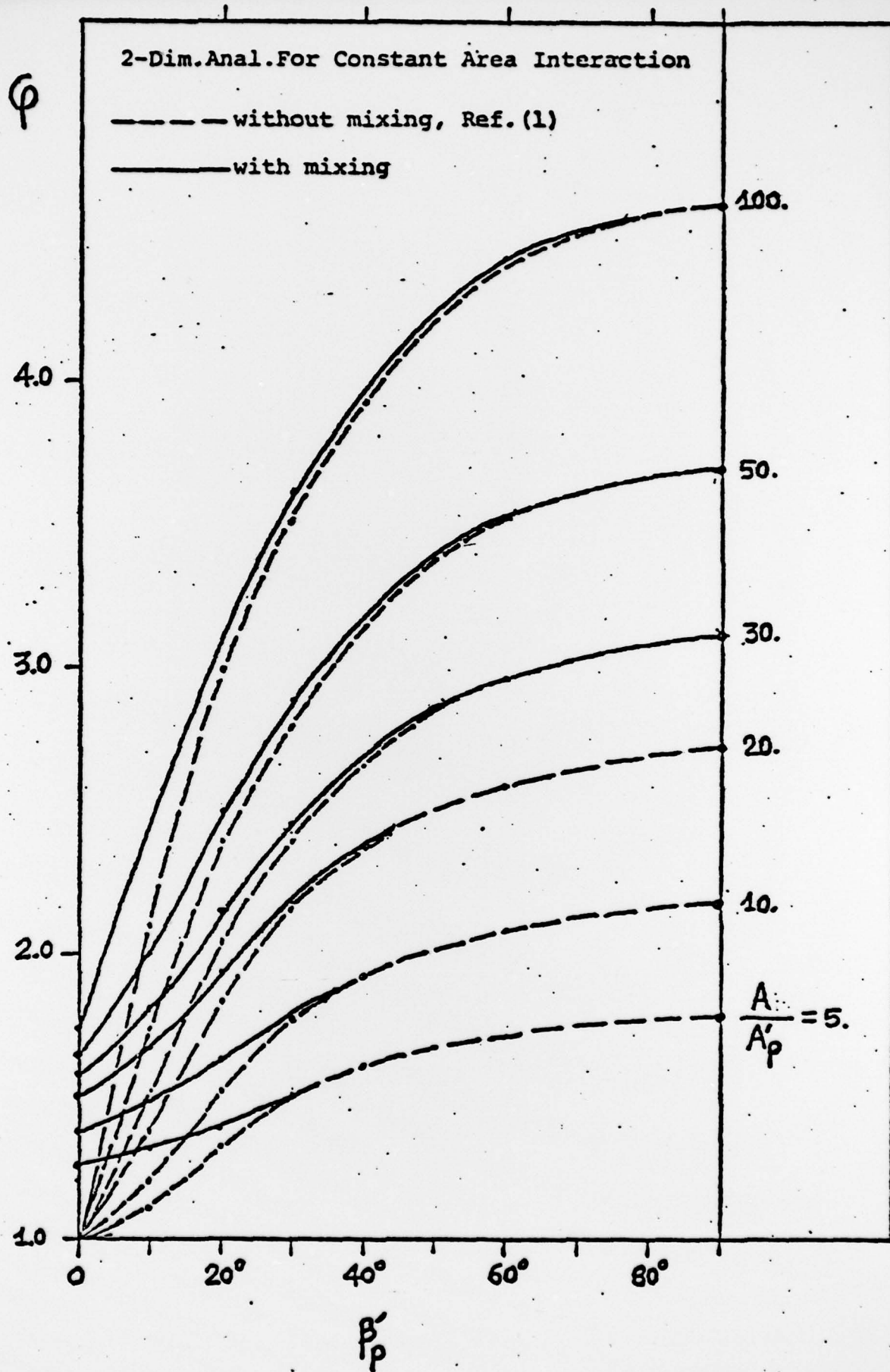
in which the primary is treated as a very thin jet successively interacting with infinitesimal layers of the secondary flow (Fig. 5). In each of these infinitesimal steps, as the two interacting flows deflect each other to a common orientation, the primary jet, which is finite, undergoes an infinitesimal deflection, and the secondary layer, which is infinitesimal, undergoes a finite deflection. The changes of angular momentum of the two flows in each step must be equal and opposite. The equation expressing this fact yields the distribution of deflections and velocities at the exit from the interaction space, and therefore also the thrust augmentation ratio.

It was felt that a more realistic analytical model would account for the part of the interaction that takes place where the secondary flow enters the space between the pseudoblades. As Fig. 6 shows, different layers in both flows undergo different histories, different deflections, and different exchanges of mechanical energy. Detailed studies of the interaction according to this model (Ref. 3) have provided a wealth of new information. They have revealed, for example, that, contrary to previous results, mixing after the mutual deflection phase is always beneficial if no account is taken of the drag and weight penalties that are associated with the required extension of the shroud (Fig. 7). Actually, beyond a certain spin angle, the benefit that can be derived from mixing becomes too small to offset these penalties.

The same analysis has also yielded some information on the progressive cross-sectional deformation of the pseudoblade







and on the effect of rotor orifice shape on rotary-jet performance.

Fig. 8 shows a comparison of the performance predictions of the above-mentioned theories.

Fig. 9 shows that what happens when any appreciable mixing is allowed to take place during the deflection phase. The effect is in this case always an adverse one, as one would expect, since any energy that is transferred through mixing during the deflection phase is energy that could have been transferred more efficiently by pressure exchange.

In a separate study (Ref. 4), a "black box" approach was used to show that the superiority of the rotary jet over the ejector can be explained as an effect of pressure exchange alone, quite apart from whatever benefit may be derived from the enhancement of mixing. The same paper also considered the effect of secondary-to-primary density ratio and showed that the effect of increasing this ratio may be beneficial or adverse, depending on the magnitude of a parameter called "pressure exchange amplitude", which is a measure of the vigor of the collision. This study was continued in Refs. 5 and 6, with the interesting result that, whereas in the ejector the best density ratio is 1.0, in the rotary jet, beyond a relatively low spin angle, the effect of an increase of density ratio is always beneficial (Fig. 10).

Attention was given to means for delaying or preventing the occurrence of flow separation over the surface of the centerbody boattail. The adverse pressure gradient that one would normally expect over such a surface is likely to be

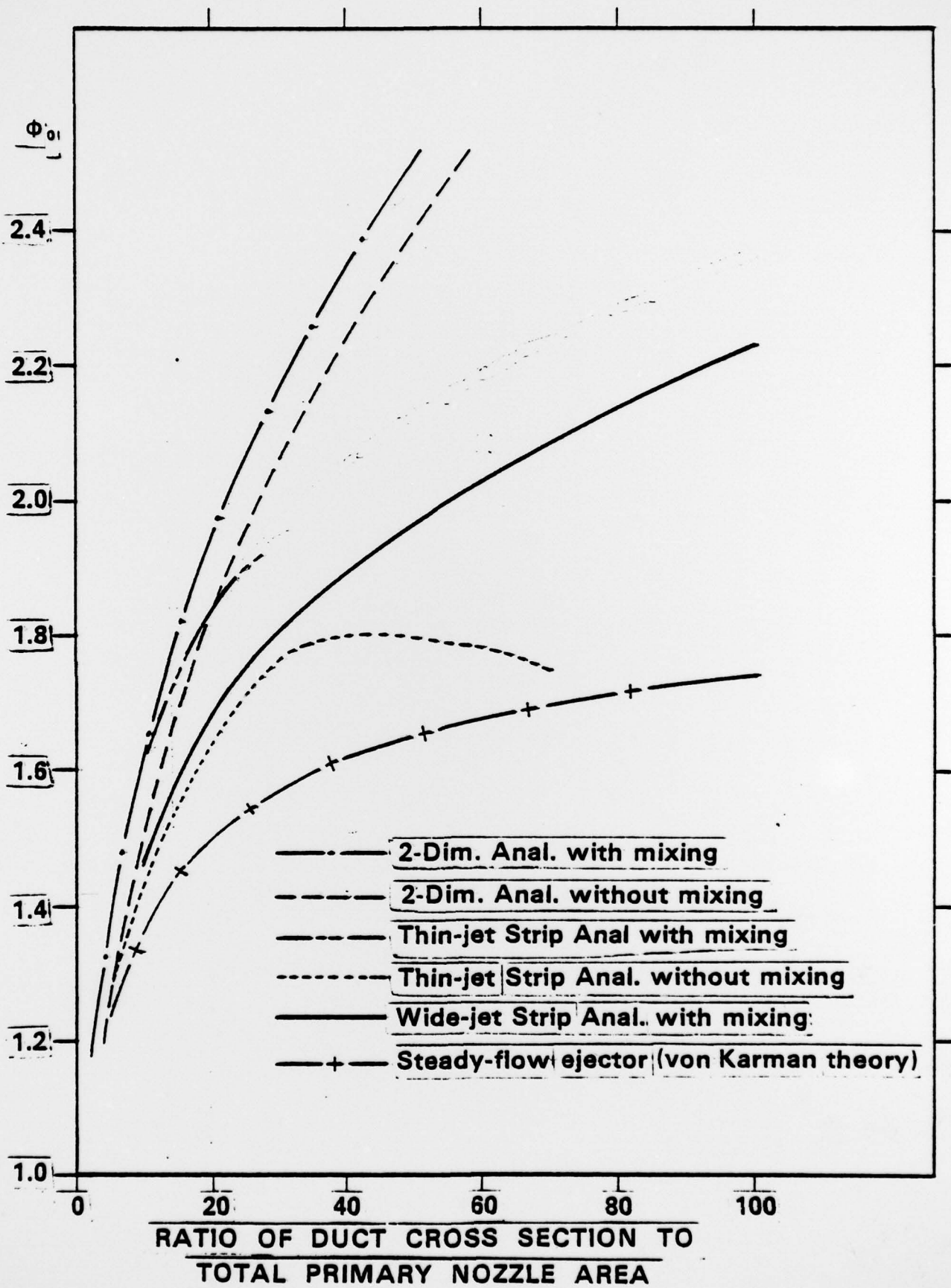
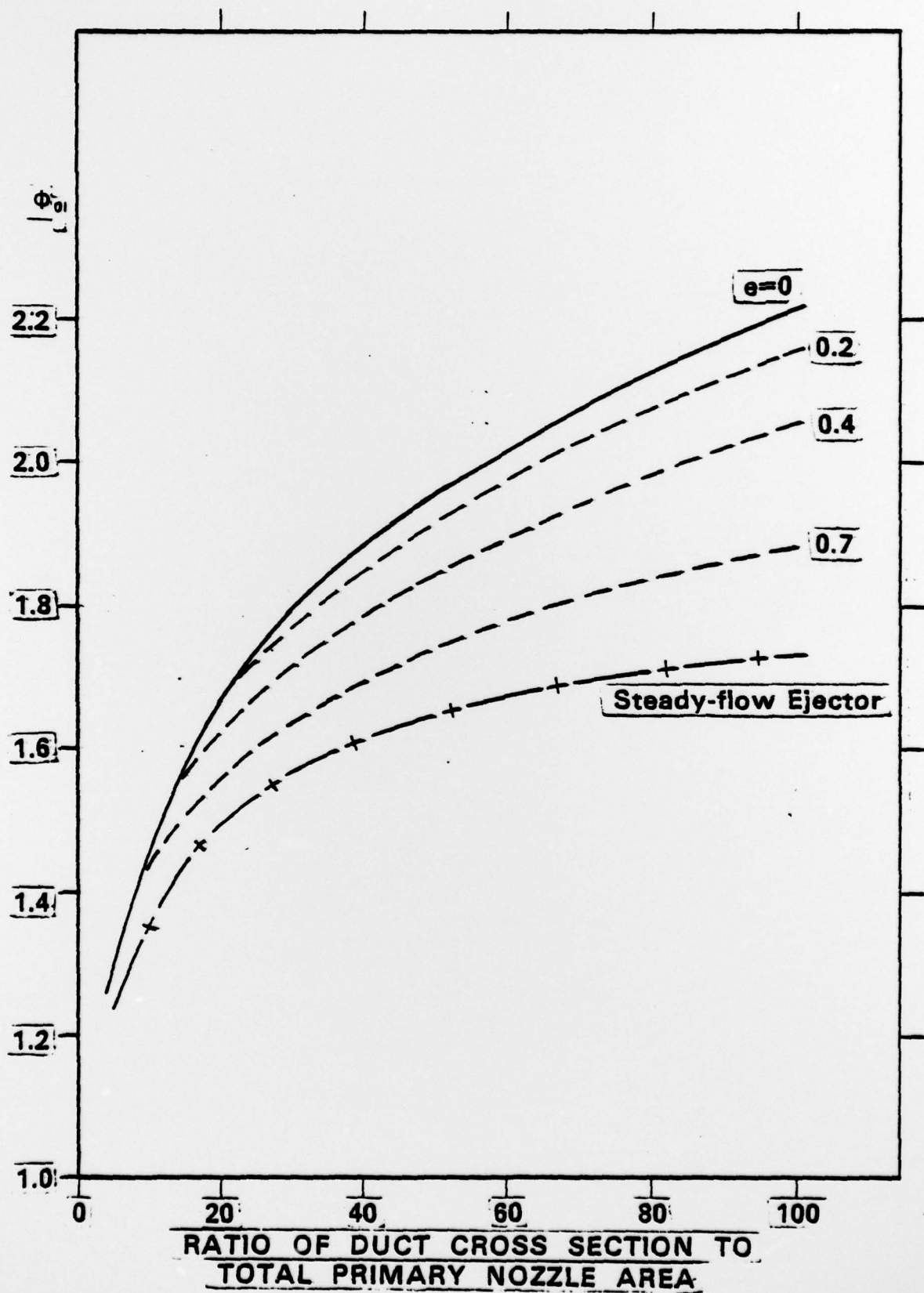
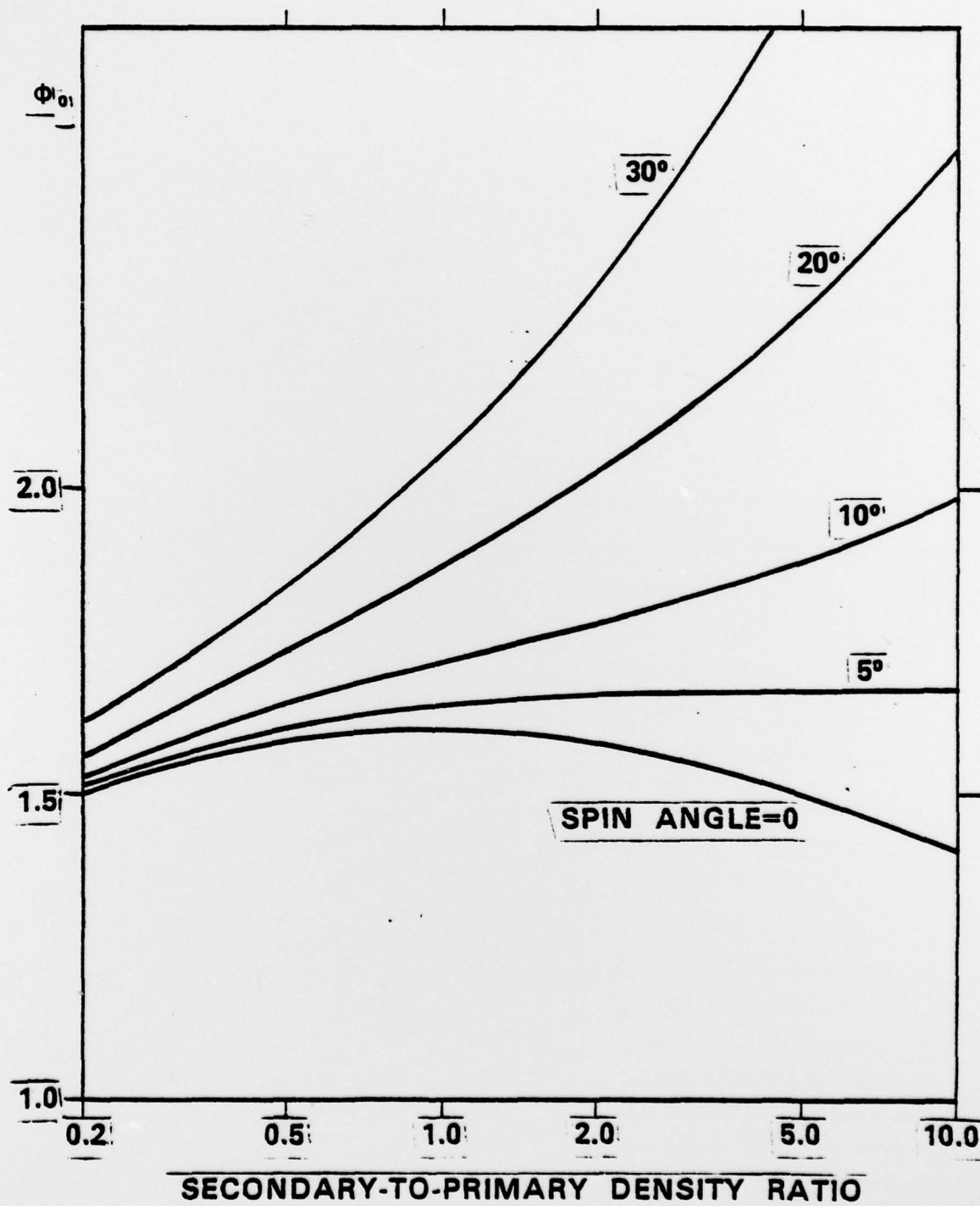


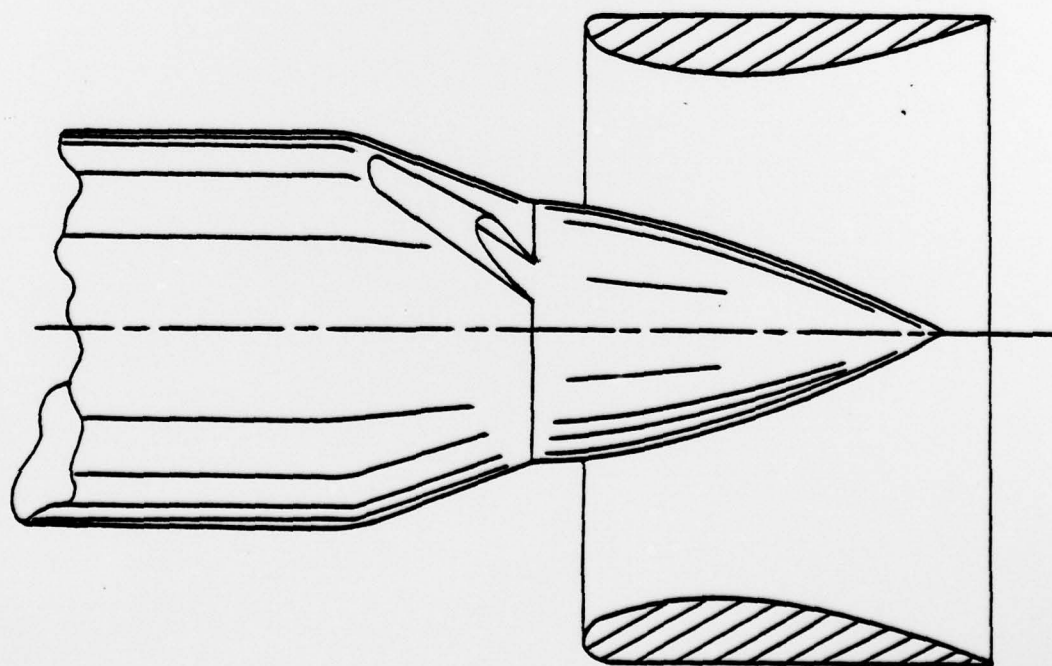
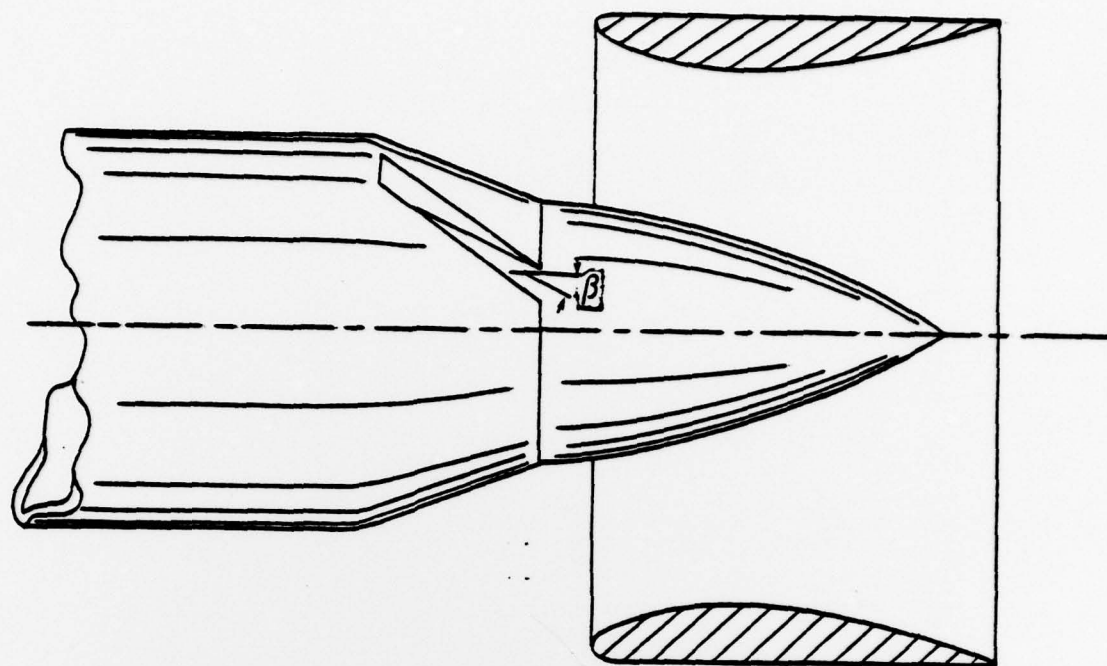
Fig. 8





aggravated, in the case of the rotary jet, by the pressure modifications which are generated by the action of the pseudo-blades. Thus, flow separation can be expected to produce a double loss of performance -- through an increase of pressure drag of the rotor and through a loss of pumping effectiveness of the pseudoblades. Fig. 11 shows a possible remedy to this difficulty -- the "core flow" arrangement, whereby a portion of the primary flow is diverted from the entrance to the rotor nozzles and is discharged instead through a central passage. This arrangement would serve the double purpose of eliminating the most critical portion of the afterbody surface and of alleviating the adverse pressure gradient, through the entrainment action of the central jet acting like the primary of an ejector. It is also expected that a further improvement of performance could be obtained by pumping air into the water flow in the central passage. The core-flow arrangement is discussed and analyzed in Refs. 7,8 and 9.

As has been mentioned earlier in this report, rotary-jet performance is adversely affected by the flow distortions which accompany the interpenetration of the two interacting flows and by any mixing that may occur during their mutual deflection. Both effects may be alleviated through the use of rotor-nozzle extensions, or "hoods", as illustrated in Fig. 12, where the upper portion shows the "standard" configuration and the lower portion a hooded one. The purpose of the hoods is to shield the two flows from one another during part or all of the interpenetration phase, thus preventing or reducing the entrainment during deflection and bringing the



interaction, downstream of the hood exit, closer to the two-dimensional ideal. These benefits are, however, diminished (and may even be offset) by accompanying penalties -- lower nozzle efficiencies, probable flow separation over the hood surface, and most importantly, reduced rotor speeds.

A method is developed in Ref. 10 for an approximate determination of the "optimum" hood configuration, when such an optimum exists. The results indicate that, for example, in the case of a rotary jet with a spin angle of 20° and an area ratio (shroud exit to primary discharge) of 20, hoods extending about half-way to the shroud could increase the static thrust augmentation ratio by as much as 10 to 12.5 percent over that of the unhooded device, all else being equal. Longer hoods would reduce the thrust augmentation.

References

1. Foa, J. V., "Steady- and Cryptosteady-Flow Underwater Thrust Augmentation - Part I - Governing Equations for Isobaric Interactions," GWU Tech. Report TR-UTA-751, November 1975.
2. Costopoulos, T., "Steady- and Cryptosteady-Flow Underwater Thrust Augmentation - Part II - Numerical Results for Isobaric Interactions," GWU Tech. Report TR-UTA-762, December 1976.
3. Costopoulos, T., "A Wide-Jet Strip Analysis of Cryptosteady-Flow Thrust Augmenters - Parts 1 and 2," GWU Tech. Reports TR-UTA-771 and TR-UTA-772, March 1977.
4. Foa, J. V., "Ejectors and Rotary Jets as Thrust Augmenters," article in Marine Propulsion, edited by J. Sladky, Jr., ASME Ocean Engineering Division, December 1976.
5. Costopoulos, T., "Constant-Area Flow Interactions in Cryptosteady-Flow Thrust Augmenters," GWU Tech. Reports TR-UTA-773 and TR-UTA-774, April 1977.

6. Costopoulos, T., "A Note on Ejectors and Rotary Jets as Thrust Augmenters," GWU Tech. Rept. TR-UTA-775, May 1977.
7. Foa, J. V., "The Core-Flow Rotary Jet - A Preliminary Analysis - Part I," GWU Tech. Report TR-UTA-781, June 1978.
8. Navy Case No. 63236, "Core-Flow Rotary Jet," Patent Application filed May 29, 1979, assigned to the U.S. Navy.
9. Ganguli, U., "The Use of a Core Flow in the Rotary Jet - A Preliminary Review of the Pertinent Literature," GWU Tech. Rept. TR-UTA-792, November 1979.
10. Foa, J. V., "Effect of Primary-Nozzle Extensions on Rotary-Jet Performance," GWU Tech. Report TR-UTA-791, July 1979.

THE GEORGE WASHINGTON UNIVERSITY

BENEATH THIS PLAQUE
IS BURIED
A VAULT FOR THE FUTURE
IN THE YEAR 2036

THE STORY OF ENGINEERING IN THIS YEAR OF THE PLACING OF THE VAULT AND
ENGINEERING HOPES FOR THE TOMORROWS AS WRITTEN IN THE RECORDS OF THE
FOLLOWING GOVERNMENTAL AND PROFESSIONAL ENGINEERING ORGANIZATIONS AND
THOSE OF THIS GEORGE WASHINGTON UNIVERSITY.

BOARD OF COMMISSIONERS, DISTRICT OF COLUMBIA
UNITED STATES ATOMIC ENERGY COMMISSION
DEPARTMENT OF THE ARMY, UNITED STATES OF AMERICA
DEPARTMENT OF THE NAVY, UNITED STATES OF AMERICA
DEPARTMENT OF THE AIR FORCE, UNITED STATES OF AMERICA
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
NATIONAL BUREAU OF STANDARDS, U.S. DEPARTMENT OF COMMERCE
AMERICAN SOCIETY OF CIVIL ENGINEERS
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
THE SOCIETY OF AMERICAN MILITARY ENGINEERS
AMERICAN INSTITUTE OF MINING & METALLURGICAL ENGINEERS
DISTRICT OF COLUMBIA SOCIETY OF PROFESSIONAL ENGINEERS, INC.
THE INSTITUTE OF RADIO ENGINEERS, INC.
THE CHEMICAL ENGINEERS CLUB OF WASHINGTON
WASHINGTON SOCIETY OF ENGINEERS
FAULKNER, KINGSBURY & STENHOUSE - ARCHITECTS
CHARLES H. TOMPKINS COMPANY - BUILDERS
SOCIETY OF WOMEN ENGINEERS
NATIONAL ACADEMY OF SCIENCES, NATIONAL RESEARCH COUNCIL

THE PURPOSE OF THIS VAULT IS INSPIRED BY AND IS DEDICATED TO
CHARLES HOOK TOMPKINS, DOCTOR OF ENGINEERING
BECAUSE OF HIS ENGINEERING CONTRIBUTIONS TO THIS UNIVERSITY, TO HIS
COMMUNITY, TO HIS NATION, AND TO OTHER NATIONS.

BY THE GEORGE WASHINGTON UNIVERSITY.

ROBERT V. FLEMING
CHAIRMAN OF THE BOARD OF TRUSTEES

CLOYD H. MARVIN
PRESIDENT

JUNE THE TWENTYETH
1956

THE FOLLOWING ARE THE NAMES OF THE
ENGINEERS WHOSE NAMES ARE ON THE
PLAQUE AND THE NUMBER OF PAGES WHICH DO NOT
APPEAR IN THE RECORDS.

To cope with the expanding technology, our society must
be assured of a continuing supply of rigorously trained
and educated engineers. The School of Engineering and
Applied Science is completely committed to this ob-
jective.